TRANSIMS TRAVELOGUE

November 1996

TRANSIMS TRAVELOGUE describes current activities within the TRANSIMS project.

(LAUR-96-4003)

WHAT IS TRANSIMS?

The TRansportation ANalysis and SIMulation System (TRANSIMS) is one part of the multi-track Travel Model Improvement Program sponsored by the U.S. Department of Transportation, the Environmental Protection Agency, and the Department of Energy. Los Alamos National Laboratory is leading this major effort to develop new, integrated transportation and air quality forecasting procedures necessary to satisfy the Intermodal Surface Transportation Efficiency Act and the Clean Air Act and its amendments.

TRANSIMS is a set of integrated analytical and simulation models and supporting data bases. The TRANSIMS methods deal with individual behavioral units and proceed through several steps to estimate travel. TRANSIMS predicts trips for individual households, residents and vehicles rather than for zonal aggregations of households. TRANSIMS also predicts the movement of individual freight loads. A regional microsimulation executes the generated trips on the transportation network, modeling the individual vehicle interactions and predicting the transportation system performance. Motor vehicle emissions are estimated using traffic information produced by TRANSIMS.

PROJECT APPROACH

We are developing interim operational capabilities (IOC) to cover the major TRANSIMS components: Household and Commercial Activity Disaggregation, Intermodal Route Planner, Transportation Microsimulation, and Environment (primarily air quality). As each IOC is ready and with the collaboration of a selected MPO, we will complete a specific case study to confirm the IOC features, applicability, and readiness. This approach should provide timely interaction and feedback from the TRANSIMS user community and interim products, capabilities, and applications.

The Traffic Microsimulation is emphasized in the first IOC, which we are testing currently. We are working with the selected MPO, North Central Texas Council of Governments (Dallas-Fort Worth), on the case study that the IOC should support.

CELLULAR AUTOMATA MICROSIMULATION

In a previous Travelogue we discussed very generally the cellular automata (CA) approach to traffic microsimulation. In this Travelogue we present additional detail about the CA methods developed for the current TRANSIMS IOC and applied in the Dallas-Fort Worth case study. The following discussion describes the fundamental model, the emergent traffic dynamics, its theoretical basis, possible extensions, calibrations, and data smoothing for emissions calculations. The discussion is based primarily on the work of Kai Nagel and his collaborators documented in the references following this article. This CA model also is often called the particle hopping model.

BASIC MODEL

The fundamental CA model considers a single-lane freeway. The freeway length is sectioned into an array of cells of uniform length. Each cell's length is the average distance (approximately 7.5 m) between vehicles when traffic is at a complete standstill, that is, in jammed traffic. A cell may be empty or contain a vehicle. If it contains a vehicle, the vehicle has an integer velocity between zero and a maximum velocity, Vmax = 5. The integer velocity represents the number of cells that the vehicle moves the next step. The step size is exactly one second, in which case Vmax corresponds to 135 km/hour, or about 84 mph. This step size abets fast computation because the updated vehicle position is computed by integer arithmetic and without multiplication of velocity and time step.

Updating the vehicle's next velocity and position is quite simple. First, we define the number of unoccupied cells ahead of the vehicle as its "gap." Then, we update the velocity by accelerating to the maximum velocity without running into the vehicle ahead:

$$V(t+1) = \min [V(t) + 1, Vmax, gap].$$

But, with probability P, we reduce this tentative velocity by one (without going backwards):

$$V(t+1) = \max[V(t+1) - 1, 0].$$

Finally, we update the vehicle's position:

$$X(t+1) = X(t) + V(t+1).$$

This rule set is called the Nagel-Schreckenberg model. The random velocity reduction process captures driver behavior such as free-speed driving fluctuations, non-deterministic accelerations, and overreactions when braking. With a deceleration probability of 0.5, the average free speed is approximately 75 mph.

EMERGENT TRAFFIC DYNAMICS

This simple model produces dynamics observable in everyday freeway traffic. First, we can display an individual vehicle's movement in space and time as shown in Figure 1. Vehicles moving at constant velocity leave straight-line tracks slanting downward to the right. A stopped vehicle moves in time, but not in space, creating a vertical line. The figure shows the spontaneous formation of well-known traffic shock waves that propagate backward in space.

This model also produces the fundamental flow-density relationship shown in Figure 2 where density has been normalized to 1.0 for a completely jammed, nonmoving system. A comparable plot can be generated from real traffic measurements. At low densities, flow increases linearly with more vehicles in the system. Near a density of 0.1 the system achieves maximum throughput or 'capacity,' but the flow is quite chaotic and its variability increases dramatically. In this density region the average travel time increases, and the travel time variance jumps tremendously. At higher densities traffic disturbances spread throughout the system until the system comes to a complete standstill at a density of 1.0.

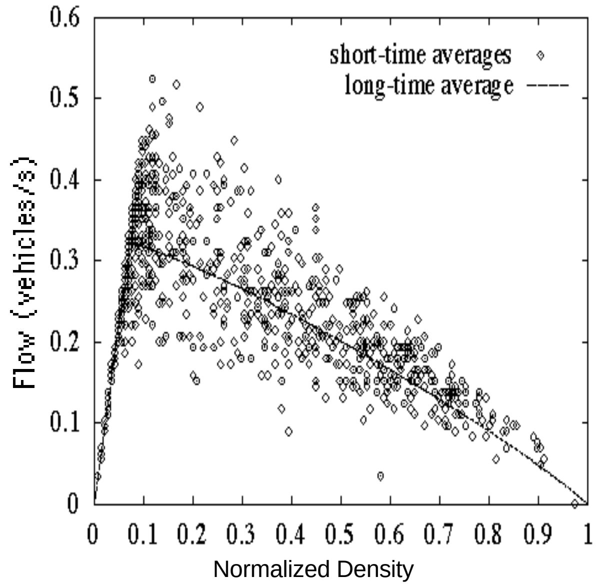

Figure 2

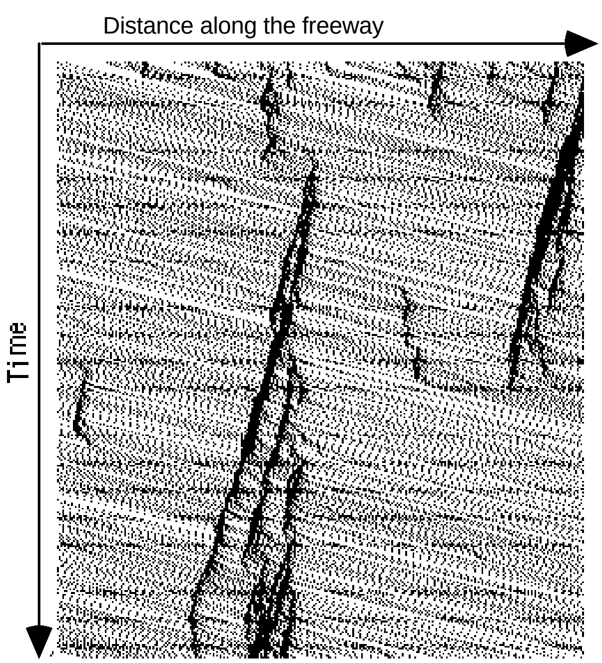

Figure 1

CA model results illustrate that the most efficient state from a traffic flow perspective is at the transition between low-density free flow and high-density, long-lifetime traffic jams. But, in this state spontaneous small fluctuations can cause large emergent traffic jams. Furthermore, as seen in Figure 1 jams themselves cause branching jam waves commonly observed as stop and go traffic. Jam wave perseverance and repeated branching produce correlated jam waves even though, from a traveler's viewpoint, their relative spatial separation may indicate no apparent common cause.

CAR-FOLLOWING MODELS

We compared the cellular automata approach with car-following models for vehicular traffic. Car-following models typically consider following distances, time headways, driver reaction times, vehicle inertia, etc. The inherent one-second time step of the CA model implicitly represents driver/vehicle reaction time delays and minimum following times. Furthermore, a local vehicle control system, that is, an adaptive "driver" who reacts to his environment, emerges from the simple CA rules. The "driver" exhibits a breadth of responses (velocity adjustments), dependent on his current velocity and gap. Thus, this controller contains a higher fidelity representation than apparent in the simple rule set.

It is not intuitively obvious that the hopping behavior of an individual CA vehicle traversing a roadway network bears resemblance to reality. In one sense we are not concerned with the individual vehicle's behavior. We are concerned whether the behavior of the ensemble of CA vehicles produces properties we can compare with measured traffic dynamics and whether we can use these properties to derive information about the performance of the transportation system. The CA model serves this function and computes fast, necessary to compute traffic flow over vast metropolitan transportation networks. Furthermore the simple CA rule set has "driver" characteristics, and careful analysis shows that the CA model can be considered a model of a driving model.

CLASSICAL FLUID DYNAMICS MODELS

Simplifications of this CA model correspond to certain cases of the Lighthill-Whitham theory, used in traffic theory for over 40 years. For instance, a CA model with Vmax=1 and random movement of vehicles to unoccupied adjacent cells corresponds in the limit to Lighthill-Whitham theory with added noise and diffusion and specialized to the Greenshields flow-density relation where flow = $\rho(1-\rho)$. If we leave Vmax=5 and remove the random component, the model corresponds to the fluid-dynamics continuity equation with a wave velocity of Vmax in light traffic and -1 in heavy traffic. This is Lighthill-Whitham theory with another flow-density relation but without noise or diffusion. Thus one can show that certain aspects of the CA model traffic jam dynamics are phenomenologically the same as in fluid-dynamics traffic models. Yet, the CA model includes fluctuations, which fluid dynamics theories do not.

EXTENSIONS

The basic Nagel-Schreckenberg CA rule set does not produce the close-following behavior usually observed in high-speed traffic. As a result, the maximum capacity displayed by the model is somewhat lower than measured on single and multiple lane roads. This model disparity can be overcome by redefining the current vehicle's gap to account for the next vehicle's velocity and gap.

The coarseness of the basic CA grid and update rules can cause concerns about spatial resolution. For example, a significant portion of the traffic may comprise vehicles larger than the cell size, or the single step accelerations may be excessive for emissions modeling, or the speed variability may be excessive for local street speed limits (Vmax). Finer spatial resolution can be obtained with further grid subdivision, but must carefully maintain the model implicit features such as reaction times, following times, and jam spacings. The rules themselves must account for vehicle lengths and jam densities whereas previously the vehicle lengths and jam densities were implicit in the grid spacing and the rules.

A major extension is to model traffic on multiple lane roads in which vehicles change lanes and pass other vehicles. Now the rules consider not only the vehicle's gap ahead, but also the adjacent lane cell occupancies in both directions (to avoid sudden stops and rear-end collisions). Various rule sets can be devised, but a simple one is to move to an unoccupied adjacent cell in the adjacent lane if:

V(t+1) > gap ahead in current lane, and

V(t+1) < gap ahead in adjacent lane, and

Vmax < gap behind in adjacent lane.

To keep vehicle platoons from bouncing between lanes, we add an additional requirement that lane changing also occurs randomly with some probability. After the lane change, the Nagel-Schreckenberg rules are applied as before.

A consideration for the multiple lane rules is whether to bias the traffic to use the right lane in the absence of other traffic constraints. Some CA rule implementations may inherently contain a lane bias in which the results depend on the update order for lanes or vehicles. If such lane asymmetries are undesirable or don't match lane usage or lane change measurements, the update order may be chosen randomly with probabilities that yield the desired behavior.

Not all motorized travel occurs on a freeway. A TRANSIMS street intersection is designed to capture the associated time delay, not the detailed turning dynamics or the intersection geometry other than possible turn bays and merge lanes. The intersection model contains allowed movements from incoming to outgoing lanes. Signalized intersections have timing and phasing plans with protected and unprotected movements. Unsignalized intersections may have stop, yield, or no signs. CA vehicles within the intersection enter buffers that capture the delay associated with passing through the intersection. Bufferless intersections assure that a freeway-ramp intersection does not perturb the CA freeway dynamics in the absence of ramp traffic. Entry onto a new roadway segment (link) requires a gap in the targeted cells, and unprotected entry also requires a gap in the traffic competing for the same road and a gap in cross traffic.

We are not developing TRANSIMS just to replicate traffic dynamics, but to examine the relationships and interactions between the transportation system and the traveling population. To understand how the transportation system affects individuals and the decisions they make about traveling, we must follow each individual's travel. Thus, each traveler has a trip plan defining his planned departure time and detailed route and transportation modes. For this IOC the trip plan is assigned to the CA vehicle. Whenever the CA vehicle enters a new link, the trip plan's next link and the next intersection's allowed movements establish the "plan lane(s)" in which the vehicle must be to stay on the plan. Thus, in addition to the basic lane changing rules, being in the proper "plan lane" is another reason for changing lanes. As the vehicle nears the intersection, the "plan lane" rule gradually overrides the other rules that may otherwise inhibit lane changing (except if the adjacent cell is currently occupied).

CALIBRATIONS

Before the CA microsimulation can execute an arbitrary demand on a complex roadway network, it should perform properly in simple controlled situations. Then we would be assured that the CA microsimulation would not cause unrealistic or confusing results in complex situations. So, we designed several simple traffic experiments with controlled demand to calibrate the CA microsimulation. As shown in Figures 1 and 2 a single-lane circle with various traffic densities calibrates the car-following behavior. We use two- and three-lane circles to calibrate lane changing behavior and lane usage as well as to establish the flow-density relation for multi-lane traffic. In another test, vehicles with specified plans through an intersection randomly begin on one of three lanes (left, through, right) heading toward the intersection to verify the model's plan-following capability.

We designed an intersection with traffic merging onto a major highway, measured the merging-traffic volume as a function of the known through-traffic volumes, and obtained results comparable to Highway Capacity Manual data. Similarly, for left turns against oncoming traffic, we measured turn volumes against known oncoming traffic volumes and obtained results comparable to Highway Capacity Manual data as well as to results from another microsimulation method. We also measured the headway distribution of vehicles leaving an intersection and obtained results similar to actual traffic measurements. Such calibration experiments are the start of a suite of tests to verify the CA microsimulation performance for a variety of situations.

EMISSIONS IMPLICATIONS

Direct observance of the CA vehicle hopping motion gives quantum velocities and accelerations. These velocities and accelerations are unrealistic for emissions model input. We are developing an approach using a Kalman filter to produce realistic, smoothed vehicle trajectories for the emissions module. The Kalman filter is designed for a physical process that has random elements and is observed with a noisy measuring device. We developed a formulation in which we estimate the fraction of aggressive drivers and the degree of their aggressiveness as expressed by their desired accelerations at a given speed.

We tested the formulation against arterial and freeway segments drawn from the California Air Resources Board data. The model addresses diverse driving situations, although further refinement may be useful. The situations we have modeled so far include arterial traffic with some vehicles starting from a stop and others continuing through a traffic light, uncongested freeway traffic and very congested freeway traffic.

In one idealized circumstance we used data from three cities to define conditional probabilities of accelerations among vehicles that had started from a stop and consistently accelerated to freeway speeds. We wanted acceleration patterns appropriate to uncongested conditions. However the procedure selected a very aggressive subset of the drivers.

In the test we used the actual speeds and accelerations as the desired driving behavior and mapped the trajectories into 7.5-m CA cells with corresponding speed intervals. Using the Kalman filter, we calculated smoothed trajectories and compared them to both the real trajectories and the CA trajectories for the same aggressiveness. The Kalman filter produced very accurate representations of the speeds and emissions from vehicles under these ideal conditions.

SUMMARY

The cellular automata approach to traffic microsimulation produces traffic dynamics typical of that observed on freeways. It is computationally fast so that major metropolitan region traffic can be simulated in reasonable times. It has elements of car-following and fluid-dynamics traffic models, but has advantages over both. It has been extended to multiple lanes, city street driving, and trip plan following. Potential limitations of the basic model can be overcome by additional extensions. We have a test suite to calibrate the model against desired behavior and real data. Techniques exist to smooth the raw CA output for emissions modeling. In conclusion, the CA model has the attributes required for the TRANSIMS traffic microsimulation.

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FURTHER INFORMATION

For further information about the TRANSIMS program, please contact:

Dr. LaRon L. Smith
Los Alamos National Laboratory
Mail Stop F606
PO Box 1663
Los Alamos, New Mexico 87545

Phone: 505-665-1286
Fax: 505-665-5249
E-mail: llsmith@lanl.gov